

WHAT IS CLAIMED IS:

1. A method of improving an image by transforming an intensity histogram thereof, the method comprising:

(a) fitting the intensity histogram to a sum of a plurality of localized functions;

(b) using said plurality of localized functions to define a plurality of localized intensity histograms;

(c) for each localized intensity histogram, performing at least one image enhancement procedure, thereby providing a plurality of improved localized intensity histograms; and

(d) combining said plurality of improved localized intensity histograms, thereby transforming the intensity histogram of the image.

2. The method of claim 1, wherein each localized function of said plurality of localized functions is independently selected from the group consisting of a Gaussian function, a Lorentzian function, a hyperbolic secant function, a logistic distribution, a Fourier transform and a wavelet transform.

3. The method of claim 1, wherein each localized intensity histogram of said plurality of localized intensity histograms is characterized by an intensity range having a minimal intensity value and a maximal intensity value, such that at least one of said minimal and maximal intensity values coincides with an intersection point between two localized function of said plurality of localized functions.

4. The method of claim 1, wherein said plurality of localized functions comprises a first localized function, a second localized function and a third localized function, and further wherein said plurality of localized histograms comprises a first localized histogram, a second localized histogram and a third localized histogram.

5. The method of claim 1, wherein said at least one image enhancement procedure is selected so as to enlarge a relative portion of a high-intensity region of the intensity histogram.

6. The method of claim 3, wherein each image enhancement procedure of said at least one image enhancement procedure is independently selected from the group consisting of histogram equalization and histogram specification.

7. The method of claim 6, wherein said plurality of localized functions comprises a first localized function, a second localized function and a third localized function, and further wherein said plurality of localized histograms comprises a first localized histogram, a second localized histogram and a third localized histogram.

8. The method of claim 7, wherein said histogram equalization is performed on said first localized histogram and said second localized histogram, and said histogram specification is performed on said third localized histogram.

9. The method of claim 8, further comprising reducing a range of said first localized histogram.

10. The method of claim 9, further comprising expanding a range of said second localized histogram.

11. The method of claim 7, further comprising linearly spreading intensity values over respective intensity ranges of said first and said second localized histogram.

12. The method of claim 7, further comprising quadratically spreading intensity values over an intensity range of said third localized histogram.

13. The method of claim 7, further comprising applying a low-pass filter on at least a portion of the intensity histogram, subsequently to said step of combining said plurality of improved localized intensity histograms.

14. The method of claim 13, wherein said low-pass filter is selected from the group consisting of a binomial filter and a Gaussian filter.

15. The method of claim 1, wherein the image is a moving image characterized by a plurality of picture-elements, said moving image being formed of a set of still-images.

16. The method of claim 15, wherein said moving image comprises a cine image.

17. The method of claim 16, wherein said cine image comprises an ultrasound cine-loop image.

18. The method of claim 17, wherein said ultrasound cine-loop image comprises an echocardiograph cine-loop image.

19. The method of claim 15, further comprising calculating, for each picture-element of said plurality of picture-elements, a set-averaged intensity value, thereby providing an average intensity matrix representing said moving image, and using said average intensity matrix to construct the intensity histogram.

20. The method of claim 19, further comprising removing clutter from the image.

21. The method of claim 20, wherein said removing said clutter from the image comprises:

calculating a statistical deviation for each picture-element over the set of still-images, thereby providing a statistical deviation matrix having a plurality of matrix-elements; and

determining, for each picture element, whether a respective matrix-element of said average intensity matrix is above a first intensity threshold and whether a respective matrix-element of said statistical deviation matrix is below an additional intensity threshold, and if so then marking said picture-element as a clutter picture-element in the image.

22. The method of claim 21, wherein said calculating said statistical deviation for each picture-element over the set of images, comprises calculating a mean-square-error of a respective matrix element of said average intensity matrix.

23. The method of claim 21, further comprising calculating said first intensity threshold, wherein said first intensity threshold is defined as an intersection point between two localized functions of said plurality of localized functions.

24. The method of claim 21, further comprising:
using said statistical deviation matrix to construct a second intensity histogram;
fitting said second intensity histogram to a second sum of a plurality of localized functions; and

calculating said additional intensity threshold, wherein said additional intensity threshold is defined as an intersection point between two localized functions of said plurality of localized functions of said second sum.

25. The method of claim 21, further comprising outlining at least one region in the image, and assigning to each clutter picture-element an intensity value corresponding to a location of said clutter picture-element relative to said at least one region.

26. The method of claim 25, wherein said outlining at least one region comprises:

applying a thresholding procedure to said set of still-images in a Boolean manner, so as to construct at least one binary matrix having a plurality of binary-valued matrix-elements; and

for each binary matrix of said at least one binary matrix, clustering said binary matrix, so as to obtain at least one cluster of matrix-elements having a predetermined polarity, and marking picture-elements corresponding to at least a portion of matrix-elements enveloping said at least one cluster as outlining picture-elements;

thereby outlining the at least one region.

27. A method of detecting clutter in a set of images arranged grid-wise in a plurality of picture-elements, each image being represented by a plurality of intensity values over said grid, the method comprising:

(a) calculating a set-averaged intensity value for each picture-element, thereby providing an average intensity matrix having a plurality of matrix-elements;

(b) calculating a statistical deviation for each picture-element over the set of images, thereby providing a statistical deviation matrix having a plurality of matrix-elements;

(c) determining, for each picture element, whether a respective matrix-element of said average intensity matrix is above a first intensity threshold and whether a respective matrix-element of said statistical deviation matrix is below an additional intensity threshold, and if so then marking that said picture-element as a clutter picture-element in the set of images.

28. The method of claim 27, wherein the set of images forms a moving image.

29. The method of claim 28, wherein said moving image comprises a cine image.

30. The method of claim 29, wherein said cine image comprises an ultrasound cine-loop image.

31. The method of claim 30, wherein said ultrasound cine-loop image comprises an echocardiograph cine-loop image.

32. The method of claim 27, wherein said calculating said statistical deviation for each picture-element over the set of images, comprises calculating a mean-square-error of a respective matrix element of said average intensity matrix.

33. The method of claim 27, wherein said first and said additional intensity thresholds are predetermined.

34. The method of claim 27, further comprising, prior to said step (c): constructing a first intensity histogram characterizing said average intensity matrix, and constructing a second intensity histogram characterizing said statistical deviation matrix.

35. The method of claim 34, further comprising, prior to said step (c): fitting said first intensity histogram to a first sum of a plurality of localized functions and using said plurality of localized functions of said first sum for calculating said first threshold; and

fitting said second intensity histogram to a second sum of a plurality of localized functions and using said plurality of localized functions of said second sum for calculating said second threshold.

36. The method of claim 34, wherein said plurality of localized functions of said first sum comprises a first localized function, a second localized function and a third localized function.

37. The method of claim 36, wherein said first intensity threshold equals an intersection point between said second and said third localized functions of said first sum.

38. The method of claim 34, wherein said plurality of localized functions of said second sum comprises a first localized function, a second localized function and a third localized function.

39. The method of claim 38, wherein said additional intensity threshold equals an intersection point between said first and said second localized functions of said second sum.

40. A method of outlining at least one region in a set of images arranged grid-wise in a plurality of picture-elements, each image being represented by a plurality of intensity values over the grid and characterized by an intensity histogram, the method comprising:

(a) calculating a set-averaged intensity value for each picture-element, thereby providing an average intensity matrix having a plurality of matrix-elements, and constructing a first intensity histogram characterizing said average intensity matrix;

(b) fitting said first intensity histogram to a sum of a plurality of localized functions, so as to provide at least one intensity threshold, each intensity threshold of said at least one intensity threshold being defined as an intersection point between two localized functions of said plurality of localized functions;

(c) for each intensity threshold of said at least one intensity threshold, applying a thresholding procedure to the set of images in a Boolean manner, so as to construct at least one binary matrix having a plurality of binary-valued matrix-elements; and

(d) for each binary matrix of said at least one binary matrix, clustering said binary matrix, so as to obtain at least one cluster of matrix-elements having a predetermined polarity, and marking picture-elements corresponding to at least a portion of matrix-elements enveloping said at least one cluster as outlining picture-elements;

thereby outlining the at least one region.

41. The method of claim 40, wherein the set of images forms a moving image.

42. The method of claim 41, wherein said moving image comprises a cine image.

43. The method of claim 42, wherein said cine image comprises an ultrasound cine-loop image.

44. The method of claim 43, wherein said ultrasound cine-loop image comprises an echocardiograph cine-loop image.

45. The method of claim 40, wherein each localized function of said plurality of localized functions is independently selected from the group consisting of

a Gaussian function, a Lorentzian function, a hyperbolic secant function, a logistic distribution, a Fourier transform and a wavelet transform.

46. The method of claim 40, wherein said plurality of localized functions comprises a first localized function, a second localized function and a third localized function.

47. The method of claim 40, further comprising removing clutter from at least one image of the set of images.

48. The method of claim 47, wherein said removing said clutter from the image comprises:

calculating a statistical deviation for each picture-element over the set of still-images, thereby providing a statistical deviation matrix having a plurality of matrix-elements and constructing a second intensity histogram characterizing said statistical deviation matrix;

fitting said second intensity histogram to a second sum of a plurality of localized functions, so as to provide at least one additional intensity threshold, said at least one additional intensity threshold being defined as an intersection point between two localized functions of said second sum; and

determining, for each picture element, whether a respective matrix-element of said average intensity matrix is above said second intensity threshold and whether a respective matrix-element of said statistical deviation matrix is below one of said at least one additional intensity threshold, and if so then marking said picture-element as a clutter picture-element in the image.

49. The method of claim 48, wherein said calculating said statistical deviation for each picture-element over the set of images, comprises calculating a mean-square-error of a respective matrix element of said average intensity matrix.

50. The method of claim 40, further comprising performing at least one morphological operation on said at least one binary matrix.

51. The method of claim 40, further comprising, for each region of the at least one region, defining an origin of the grid, said origin being defined as a central picture-element of said region.

52. The method of claim 51, further comprising transforming the grid into a polar representation using said origin of the grid, said polar representation being represented by a radial matrix and an angular matrix.

53. The method of claim 52, further comprising digitizing said radial matrix and said angular matrix using a predetermined resolution.

54. The method of claim 53, wherein the set of images forms a cine-loop image of at least the left ventricle.

55. The method of claim 54, wherein the at least one region comprises said left ventricle.

56. The method of claim 54, wherein said at least one intensity threshold comprises a first intensity threshold and a second intensity threshold, hence said at least one binary matrix comprises a first binary matrix and a second binary matrix.

57. The method of claim 56, wherein enveloping matrix elements of said first binary matrix correspond to an inner boundary of said left ventricle, and enveloping matrix elements of said second binary matrix correspond to an outer boundary of said left ventricle.

58. The method of claim 54, further comprising, for each binary matrix of said at least one binary matrix: identifying matrix-elements representing the papillary muscles and removing said identified matrix-elements from said binary matrix.

59. The method of claim 58, wherein said identification of matrix-elements representing the papillary muscles is effected by a region-growing procedure.

60. The method of claim 54, further comprising for each binary matrix of said at least one binary matrix: identifying matrix-elements representing cusps of the mitral valve, and removing said identified matrix-elements from said binary matrix.

61. The method of claim 54, wherein said identification of said matrix-elements representing said cusps of the mitral valve comprises:

calculating, for each picture-element of said plurality of picture-elements of the grid, a deviation of an intensity value of said picture-element; and

identifying matrix-elements corresponding to picture-elements having a high deviation of intensity value as matrix-elements representing said cusps of the mitral valve.

62. The method of claim 60, further comprising:

applying a set of temporal and spatial filters, so as to reject at least a few matrix-elements enveloping said at least one cluster of matrix-elements; and

assigning to picture-elements corresponding to said rejected matrix-elements interpolated intensity values.

63. An apparatus for improving an image by transforming an intensity histogram thereof, the apparatus comprising:

a fitter, for fitting the intensity histogram to a sum of a plurality of localized functions;

a histogram definer, for defining a plurality of localized intensity histograms using said plurality of localized functions; and

a histogram transformer, supplemented by an algorithm for performing at least one image enhancement procedure, for enhancing each localized intensity histogram, thereby to provide a plurality of improved localized intensity histograms, and combining said plurality of improved localized intensity histograms.

64. The apparatus of claim 63, wherein each localized function of said plurality of localized functions is independently selected from the group consisting of a Gaussian function, a Lorentzian function, a hyperbolic secant function, a logistic distribution, a Fourier transform and a wavelet transform.

65. The apparatus of claim 63, wherein each localized intensity histogram of said plurality of localized intensity histograms is characterized by an intensity range having a minimal intensity value and a maximal intensity value, such that at least one of said minimal and maximal intensity values coincides with an intersection point between two localized function of said plurality of localized functions.

66. The apparatus of claim 63, wherein said plurality of localized functions comprises a first localized function, a second localized function and a third localized function, and further wherein said plurality of localized histograms comprises a first localized histogram, a second localized histogram and a third localized histogram.

67. The apparatus of claim 63, wherein said at least one image enhancement procedure is selected so as to enlarge a relative portion of a high-intensity region of the intensity histogram.

68. The apparatus of claim 65, wherein each image enhancement procedure of said at least one image enhancement procedure is independently selected from the group consisting of histogram equalization and histogram specification.

69. The apparatus of claim 68, wherein said plurality of localized functions comprises a first localized function, a second localized function and a third localized function, and further wherein said plurality of localized histograms comprises a first localized histogram, a second localized histogram and a third localized histogram.

70. The apparatus of claim 69, wherein said histogram equalization is performed on said first localized histogram and said second localized histogram, and said histogram specification is performed on said third localized histogram.

71. The apparatus of claim 70, wherein said transformer is operable to reduce a range of said first localized histogram.

72. The apparatus of claim 71, wherein said transformer is operable to expand a range of said second localized histogram.

73. The apparatus of claim 69, wherein said transformer is operable to linearly spread intensity values over respective intensity ranges of said first and said second localized histogram.

74. The apparatus of claim 69, wherein said transformer is operable to quadratically spread intensity values over an intensity range of said third localized histogram.

75. The apparatus of claim 69, wherein said transformer is operable to apply a low-pass filter on at least a portion of the intensity histogram.

76. The apparatus of claim 75, wherein said low-pass filter is selected from the group consisting of a binomial filter and a Gaussian filter.

77. The apparatus of claim 63, wherein the image is a moving image characterized by a plurality of picture-elements, said moving image being formed of a set of still-images.

78. The apparatus of claim 77, wherein said moving image comprises a cine image.

79. The apparatus of claim 78, wherein said cine image comprises an ultrasound cine-loop image.

80. The apparatus of claim 79, wherein said ultrasound cine-loop image comprises an echocardiograph cine-loop image.

81. The apparatus of claim 77, further comprising a histogram constructor for constructing the intensity histogram of the image.

82. The apparatus of claim 81, wherein said histogram constructor comprises an average calculator, for calculating, for each picture-element of said plurality of picture-elements, a set-averaged intensity value, thereby to provide an

average intensity matrix representing said moving image; and to construct the intensity histogram using said average intensity matrix.

83. The apparatus of claim 81, further comprising a preprocessing unit, for performing at least one preprocessing operation on the set of images.

84. The apparatus of claim 83, wherein said preprocessing unit is operable to remove clutter from the image.

85. The apparatus of claim 84, wherein said preprocessing unit comprises:
a statistical deviation calculator, for each picture-element over the set of still-images, thereby to provide a statistical deviation matrix having a plurality of matrix-elements; and

electronic-calculation functionality for determining, for each picture element, whether a respective matrix-element of said average intensity matrix is above a first intensity threshold and whether a respective matrix-element of said statistical deviation matrix is below an additional intensity threshold, and if so then marking said picture-element as a clutter picture-element in the image.

86. The apparatus of claim 85, wherein said statistical deviation calculator is operable to calculate a mean-square-error of a respective matrix element of said average intensity matrix.

87. The apparatus of claim 85, wherein said preprocessing unit further comprises an intensity threshold calculator, for calculating said first intensity threshold, wherein said first intensity threshold is defined as an intersection point between two localized functions of said plurality of localized functions.

88. The apparatus of claim 87, wherein said histogram constructor is operable to construct a second intensity histogram using said statistical deviation matrix.

89. The apparatus of claim 88, wherein said fitter is operable to fit said second intensity histogram to a second sum of a plurality of localized functions.

90. The apparatus of claim 89, wherein said intensity threshold calculator is operable to calculate said additional intensity threshold, wherein said additional intensity threshold is defined as an intersection point between two localized functions of said plurality of localized functions of said second sum.

91. The apparatus of claim 85, wherein said preprocessing unit further comprises:

- an outliner, for outlining at least one region in the image; and
- intensity value assigner, for assigning to each clutter picture-element an intensity value corresponding to a location of said clutter picture-element relative to said at least one region.

92. The apparatus of claim 91, wherein said outliner comprises:

- a thresholding unit, for applying a thresholding procedure to said set of still-images in a Boolean manner, such that at least one binary matrix having a plurality of binary-valued matrix-elements is constructed; and

- a clustering unit, for clustering each binary matrix of said at least one binary matrix, so as to obtain at least one cluster of matrix-elements having a predetermined polarity, said clustering unit being operable to mark picture-elements corresponding to at least a portion of matrix-elements enveloping said at least one cluster as outlining picture-elements.

93. An apparatus for detecting clutter in a set of images arranged grid-wise in a plurality of picture-elements, each image being represented by a plurality of intensity values over said grid, the apparatus comprising:

- (a) an average calculator, for calculating a set-averaged intensity value for each picture-element, thereby providing an average intensity matrix having a plurality of matrix-elements;

(b) a statistical deviation calculator, for calculating a statistical deviation for each picture-element over the set of images, thereby providing a statistical deviation matrix having a plurality of matrix-elements;

(c) clutter identification unit, operable to determine, for each picture element, whether a respective matrix-element of said average intensity matrix is above a first intensity threshold and whether a respective matrix-element of said statistical deviation matrix is below an additional intensity threshold, and if so then to mark that said picture-element as a clutter picture-element in the set of images.

94. The apparatus of claim 93, wherein the set of images forms a moving image.

95. The apparatus of claim 94, wherein said moving image comprises a cine image.

96. The apparatus of claim 95, wherein said cine image comprises an ultrasound cine-loop image.

97. The apparatus of claim 96, wherein said ultrasound cine-loop image comprises an echocardiograph cine-loop image.

98. The apparatus of claim 93, wherein said statistical deviation calculator is operable to calculate a mean-square-error of a respective matrix element of said average intensity matrix.

99. The apparatus of claim 93, wherein said first and said additional intensity thresholds are predetermined.

100. The apparatus of claim 93, further comprising a histogram constructor, for constructing a first intensity histogram from said average intensity matrix and a second intensity histogram from said statistical deviation matrix.

101. The apparatus of claim 93, further comprising,

a fitter, for independently fitting each of said first and second intensity histograms to a sum of a plurality of localized functions; and

an intensity threshold calculator for calculating said first and said additional intensity thresholds, using said plurality of localized functions, wherein said first intensity threshold is defined as an intersection point between two localized functions of said first intensity histogram, and said additional intensity threshold is defined as an intersection point between two localized functions of said second intensity histogram.

102. The apparatus of claim 101, wherein said plurality of localized functions of said first intensity histogram comprises a first localized function, a second localized function and a third localized function, whereas said first intensity threshold equals an intersection point between said second localized function and said third localized function.

103. The apparatus of claim 101, wherein said plurality of localized functions of said second intensity histogram comprises a first localized function, a second localized function and a third localized function, whereas said additional intensity threshold equals an intersection point between said first localized function and said second localized function.

104. An apparatus for outlining at least one region in a set of images arranged grid-wise in a plurality of picture-elements, each image being represented by a plurality of intensity values over the grid and characterized by an intensity histogram, the apparatus comprising:

a histogram constructor, for constructing a first intensity histogram characterizing the set of images;

a fitter, for fitting said first intensity histogram to a sum of a plurality of localized functions;

an intensity threshold calculator, for calculating at least one intensity threshold, each intensity threshold of said at least one intensity threshold being defined as an intersection point between two localized functions of said plurality of localized functions;

a thresholding unit, for applying a thresholding procedure to the set of images in a Boolean manner using each intensity threshold of said at least one intensity threshold, such that at least one binary matrix having a plurality of binary-valued matrix-elements is constructed; and

a clustering unit, for clustering each binary matrix of said at least one binary matrix, so as to obtain at least one cluster of matrix-elements having a predetermined polarity, said clustering unit being operable to mark picture-elements corresponding to at least a portion of matrix-elements enveloping said at least one cluster as outlining picture-elements.

105. The apparatus of claim 104, further comprising an average calculator, for calculating a set-averaged intensity value for each picture-element, thereby to provide an average intensity matrix having a plurality of matrix-elements, wherein said histogram constructor is designed to construct said first intensity histogram using said average intensity matrix.

106. The apparatus of claim 104, wherein the set of images forms a moving image.

107. The apparatus of claim 106, wherein said moving image comprises a cine image.

108. The apparatus of claim 107, wherein said cine image comprises an ultrasound cine-loop image.

109. The apparatus of claim 108, wherein said ultrasound cine-loop image comprises an echocardiograph cine-loop image.

110. The apparatus of claim 104, wherein each localized function of said plurality of localized functions is independently selected from the group consisting of a Gaussian function, a Lorentzian function, a hyperbolic secant function, a logistic distribution, a Fourier transform and a wavelet transform.

111. The apparatus of claim 104, wherein said plurality of localized functions comprises a first localized function, a second localized function and a third localized function.

112. The apparatus of claim 104, further comprising electronic-calculation functionality for performing at least one morphological operation on said at least one binary matrix.

113. The apparatus of claim 104, further comprising a preprocessing unit for performing at least one preprocessing operation on the set of images.

114. The apparatus of claim 113, wherein said preprocessing unit is operable to remove clutter from at least one image of the set of images.

115. The apparatus of claim 104, wherein said clustering unit comprises an origin definer for defining, for each region of the at least one region, an origin of the grid, said origin being defined as a central picture-element of said region.

116. The apparatus of claim 115, wherein said clustering unit comprises a coordinate transformation unit for transforming the grid into a polar representation using said origin of the grid, said polar representation being represented by a radial matrix and an angular matrix.

117. The apparatus of claim 116, wherein said clustering unit comprises a digitizer for digitizing said radial matrix and said angular matrix using a predetermined resolution.

118. The apparatus of claim 117, wherein the set of images forms a cine-loop image of at least the left ventricle.

119. The apparatus of claim 118, wherein the at least one region comprises said left ventricle.

120. The apparatus of claim 119, further comprising a preprocessing unit for performing at least one preprocessing operation on the set of images.

121. The apparatus of claim 120, wherein said preprocessing unit is operable to remove, from each binary matrix of said at least one binary matrix, matrix-elements representing the papillary muscles.

122. The apparatus of claim 121, wherein said preprocessing unit is supplemented by an algorithm for performing a region-growing procedure.

123. The apparatus of claim 119, wherein said preprocessing unit is operable to remove, from each binary matrix of said at least one binary matrix, matrix-elements representing cusps of the mitral valve.

124. The apparatus of claim 123, wherein said preprocessing unit comprises: an intensity value deviation calculator, for calculating, for each picture-element of said plurality of picture-elements of the grid, a deviation of an intensity value of said picture-element, and further wherein said matrix-elements representing said cusps of the mitral valve are correspond to picture-elements having a high deviation of intensity.

125. The apparatus of claim 123, further comprising an interpolation unit for assigning interpolated intensity values to non-valid matrix-elements, said interpolation unit being operable to apply a set of temporal and spatial filters prior to said assignment so as to identify said non-valid picture-elements.